

# Shipboard Wind Profiling by Radar: Problems and Possible Solutions

Madison J. Post  
Christopher W. Fairall  
Allen B. White  
James R. Jordan  
NOAA Environmental Technology Laboratory

and

Kenneth S. Gage  
John Wilson  
Leslie M. Hartten  
NOAA Aeronomy Laboratory

325 Broadway  
Boulder, Colorado 80303

## Introduction

Using modern UHF radars to profile boundary-layer winds from ships offers many advantages. These systems are relatively small and inexpensive (20 m<sup>3</sup>, \$200K) and they can run unattended for many months in all weather conditions. Temporal and vertical resolution of the wind measurements can be as fine as 5 minutes and 60 m, respectively. Such measurements offer unparalleled, cost-effective performance for tactical operations, resource protection, forecasting, and research.

Table 1

Shipboard Radar <b>Wind</b> Profiling NOAA/ERL Experience				
<u>Year</u>	<u>Ship</u>	<u>Location</u>	<u>Months</u>	<u>Days</u>
1991	Baldrige	Miami-Puerto Rico	May	15
1991	Mauna Wave	Tiwi (0°, 140W)	Nov. - Dec,	30
1992	Baldrige	East Atlantic	May - July	90
1992	"Science 1"	Trop. West. Pac.	Nov. - Feb.	120
1992	"Exp. 3"	Trop. West. Pac.	Nov. - Feb.	120
1992	Mauna Wave	Trop. West. Pac.	Nov. - Feb.	120
1993	Titan	Channel Islands	Sept.	30
1994	Wecoma	California - Oregon	Mar. - Apr.	60
1995	Discoverer	Tasmania	Oct. - Nov.	60
1996	Discoverer	Trop. West. Pac.	Mar. - Apr.	60
1997	Knorr	N. Atlantic	Jam	30
1997	Ka'Imimoana	Cent. Eq. Pac.	- - -	---

Two of the National Oceanic and Atmospheric Administration's (NOAA) Environmental Research Laboratories, the Environmental Technology Laboratory (ETL) and the Aeronomy Laboratory(AL)

have acquired over 600 days of experience operating such profilers at sea. Table 1 lists the research campaigns by ship, location, and duration. Results from the first deployment in 1991 on the NOAA *R/V Malcolm Baldrige* are presented in Carter, et al. [1992]. Subsequent AL developments in profiler technology are summarized in Carter et al., [1995].

Our systems operate at 915 MHz and are mechanically stabilized to eliminate the effects of ship motion. They typically use phased-array antennas to transmit and receive energy along at least one pair of beams oriented about  $20^\circ$  off the vertical and along orthogonal azimuthal directions. Normally the cycling of beams along different directions also includes a vertically-oriented beam as well. The Doppler-shift of the energy scattered back from the atmosphere along all beams is determined and used with information on the ship's orientation and motion to produce estimates of earth-relative wind speed and direction at many range gates, typically encompassing the height interval 0.15 to 3.0 km. Typically we save the complete Doppler spectra of the signal in each gate, and archive the first three moments computed from the spectra as well. The first three moments of the Doppler spectra are related to backscattered energy, radial velocity, and velocity spread in the sensing volume, respectively. Time-height displays of the vertical beam spectral moments reveal interesting and useful atmospheric features, such as precipitation fall speed, melting layer, cloud bottoms and tops, and turbulence [White, et al., 1996].

## Problems

Despite the potential of this technology and its remarkably good performance during the first shipboard deployment [Carter, et al., 1992], we have subsequently learned that one must take precautions in locating the hardware onboard ships to minimize the effects of sea clutter, and in using the data products generated by the system's software, the Profiler On-line Program (POP). POP uses consensus averaging [Weber et al., 1993] of Doppler spectral moments to compute wind products, and assumes the spectra contain only atmospheric signals. When spectra are contaminated, the spectral moments, and hence the wind products, can be in error.

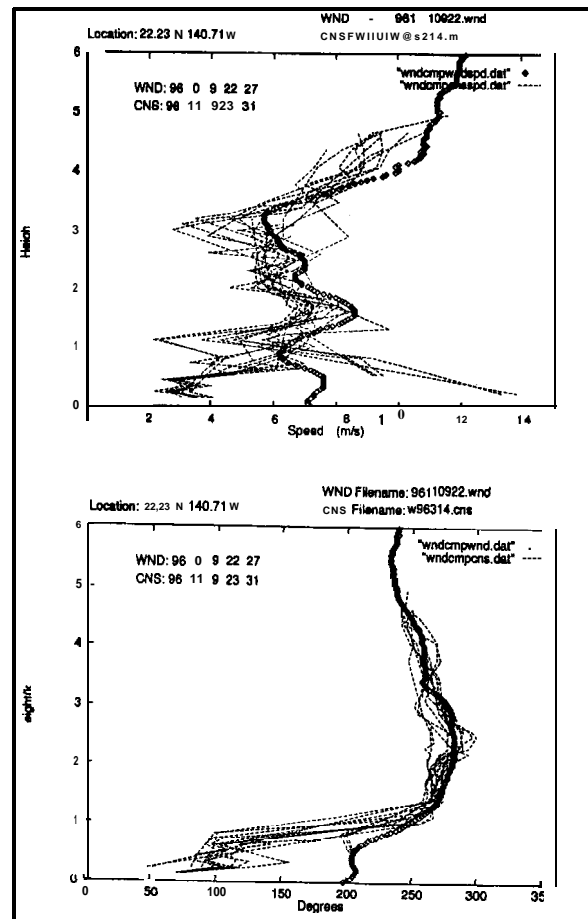


Fig. 1. Comparison of profiler-derived winds for multiple soundings (dashed lines) with a contemporaneous balloon sounding (diamond markers) from NOAA R/V *Ka'imimoana* in 1996. Low-level profiler winds are likely in error due to contamination of radar signals by sea clutter.

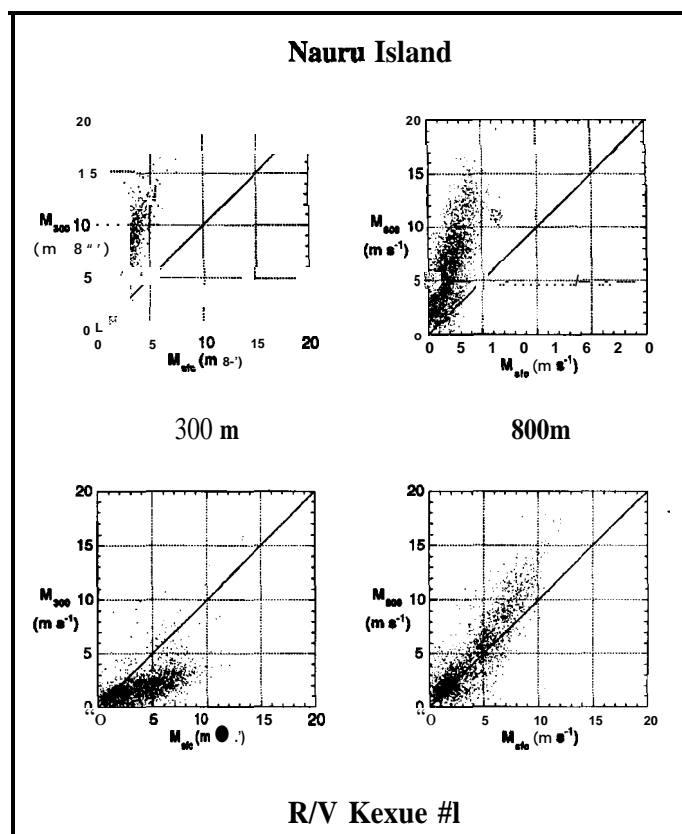


Fig. 2. Scatter diagrams of surface winds (x-axis) vs. profiler winds at altitude (y-axis) for 300 m altitude (left plots) and 800m altitude (right plots). Island winds (above) with little sea clutter show expected trends in the diagrams while ship-baaed winds (below) show effects of sea clutter contamination.

describe other similar intercomparisons made during the Coupled Ocean-Atmosphere Response Experiment (COARE) of the Tropical Ocean and Global Atmosphere (TOGA) program. From March to April, 1996, we deployed another stabilized 915 MHz wind profiling system at sea. We took care to position it nearly optimally low on the rear fantail of NOAA R/V *Discoverer*, and we installed diffraction-softening baffles on top of the standard clutter fences. This was our most successful deployment since the initial one on the *Malcolm Baldrige*. Table 2 compares radar-derived winds with both surface and balloon winds. Note that although the lower radar gates display possible negative biases in wind velocity estimates, the biases are not as large, or as high-reaching, as in Fig. 1.

Other problems that are encountered by all radar wind profilers, including those at sea, are radio frequency interference and contamination by fliers (birds and planes). Both types of non-atmospheric signals can enter through sidelobes or the main beam. We do not have statistical analyzes of the effects of these contaminants, but in general the effects are more intermittent and cause larger errors than sea clutter.

Fig. 1 displays the effects that sea clutter often has on the radar-estimated wind products. Here we compare winds measured by ship-launched radiosondes with the radar-derived winds, for a research cruise of the NOAA R/V *Ku'imimoana* in 1996 in the central Pacific. Since sea clutter often appears near zero frequency in the Doppler spectrum, it biases the wind estimates low. This creates underestimates of wind speed, and some error in wind direction, primarily at short ranges (low altitudes) where clutter can dominate the desired atmospheric signals from the main beams. In a separate study of island-based and ship-borne profilers deployed November, 1992, to February, 1993, in the western Pacific, Hartten [1996] compared radar-derived winds in the lower gates with surface winds. One expects the surface winds to be lower than winds from the lowest radar gates, and to see a consistent pattern of differences vs. altitude for both platforms. Instead we see more spread in the scatter diagrams, and surface winds up to  $5 \text{ m s}^{-1}$  stronger than low-level profiler winds, for the ship-borne systems, as depicted in Fig. 2. Riddle et al. [1996]

Table 2

### Correlation between CSP 915-MHz radar-derived winds and

1) Surface Winds

	Gate 1 (120 m)	Gate 2 (219 m)	Gate 3 (318 m)	Gate 4 (417 m)	Gate 5 (516 m)
N	237	257	459	517	535
R*	0.61	0.63	0.64	0.68	0.65
U <sub>s</sub>	4.8	4.9	5.3	5.4	5.5
Bias	-1.5 In/s	-0.9	+0.2	+0.7	+1.2

2) Rawinsondes

	Gate 1-5 (100-500 m)	Gate 6-10 (600-1000 m)	Gate 11-15 (1100-1500 m)	Gate 16-20 (1600-2000 m)
N	460	601	604	578
R*	0.51	0.74	0.78	0.71
U <sub>s</sub>	6.2	7.2	7.5	7.2
Bias	-0.9 I-III s	+0.3	0.0	0.0

N = # Cases      R<sup>2</sup> = Correlation Coefficient      U<sub>s</sub> = 1) Surface Mean Wind; 2) Balloon Mean Wind;  
Both 1) and 2) only for cases involved in N.

## Solutions

To minimize contamination of the radar's Doppler spectra by sea clutter, one must take care in siting the profiler to avoid reflection of the antenna's sidelobes by ship structures, because the radar then "sees" the surface of the ocean. This typically involves placing the profiler as far away as possible from tall structures, orienting its orthogonal beams 45° from the centerline of the ship, and keeping it as low as possible on the ship (as close to water level as feasible). It might also prove helpful to install diffraction-softening baffles along the upper edges of the radar's clutter screens, as we did on the Discoverer deployment. We have found mechanical (gyro) stabilization of a horizontally-oriented phased array antenna panel to be quite satisfactory, but such stabilization adds to the bulk and price of the system. We are investigating the feasibility of using unstabilized antennae (e.g., on buoys) and computer-correcting for instantaneous platform motion and orientation, for both ship and buoy applications.

However, even for optimal antenna designs there always will remain antenna sidelobes, due to the antenna's finite size and the radar wavelength (.33 m). Contamination of atmospheric signals, which are quite weak, can occur through the sidelobes or even the main beam (in the case of fliers and RFI). “Therefore, advanced signal processing is needed to decontaminate the data stream before Doppler spectra and spectral moments are computed. To this end, the labs are producing and testing several new algorithms, together with new operating systems to more efficiently implement them. Jordan et al. [1996] are applying wavelet transforms to the radar time series to remove sea clutter and flier contamination, with notable success. Merritt [1995] has created an algorithm using statistical techniques to automatically edit the resultant spectra and remove more of the erroneous data.

Finally, Weber et al. [1993] use time-height continuity editing to cleanup data at the moment level, before consensus winds are computed. The POP program is being upgraded and modularized to permit integration of some of the new algorithms, and an entirely new operating system named CASPER (Control, Acquisition, and Signal Processing Engine for Radar) is also being developed and tested. For a description of CASPER visit web site <http://ics.etl.noaa.gov/>.

## Summary

We have operated 915 MHz radar wind profiling systems onboard moderate- to large- sized research vessels (100-300 ft long) over a span of 5 years, accumulating more than 600 days of operating experience at sea in a wide range of weather conditions. Our conclusion is that these systems are robust and that they can provide reliable, continuous, unattended wind observations from about 150 m to more than 3 km altitude. However, because of sea clutter and other possible contamination of radar signals, one must be cautious and not blindly use wind products from the lower gates. Higher gates are typically unaffected by contamination. We have found that proper siting of the profilers away from tall structure and as low as possible on the ship is critical in minimizing the introduction of sea clutter through reflected antenna sidelobes. And we are working to develop, test, and implement new signal processing techniques and operating systems to minimize the deleterious effects of sea clutter and other interferences on profiler wind products.

## References

Carter, D. A., W.L. Ecklund, K.S. Gage, M. Spowart, H.L. Cole, E.F. Chamberlain, W.F. Dabberdt, and J. Wilson, 1992: "First test of a shipboard wind profiler," *Bull. Am. Met. Soc.*, 73, 1587-1592.

Carter, D.A., K.S. Gage, W.L. Ecklund, W.M. Angevine, P.E. Johnston, A.C. Riddle, J. Wilson, and C.R. Williams, 1995: "Developments in UHF lower tropospheric wind profiling at NOAA's Aeronomy Laboratory," *Radio Science*. 30,977-1001.

Hartten, L.M., 1996: "Reconciliation of surface and profiler winds at 1SS sites," submitted to *J. Atmos. and Ocean. Tech.*, July 1996.

Jordan, J. R., R.J. Latatits, and D.A. Carter, 1996: "Removing ground and intermittent clutter contamination from wind profiler signals using wavelet transforms," submitted to *J. Atmos. oceanic Tech.*

Merritt, D. A., 1995: "A statistical averaging method for wind profiler Doppler spectra," *J. Atmos. Oceanic Tech.*, 12,985-995.

Riddle, A. C., W.M. Angevine, W.L. Ecklund, E.R. Miller, D.B. Parsons, D.A. Carter, and K.S. Gage, 1996: "In situ and remotely sensed horizontal wind and temperature intercomparisons obtained using Integrated Sounding Systems during TOGA COARE." *Beitr. Phys. Atmosph.*, 69,49-61.

Strauch, R. L., D.A. Merritt, K.P. Moran, K.B. Earnshaw, and D. VanDe Kamp, 1984: "The Colorado wind profiling network," *J. Atmos. and Oceanic Tech.*, **1**,37-49.

Weber, B. L., D.B. Wuertz, D.C. Welsh, and R. McPeck, 1993: "Quality controls for profiler measurements of winds and RASS temperatures," *J. Atmos. and Oceanic Tech.*, **10**,452-464.

White, A. B., C.W. Fairall, A.S. Frisch, B.W. Orr, and J.B. Snider, 1996: "Recent radar measurements of turbulence and microphysical parameters in marine boundary layer clouds," *Atmos. Res.*, **40**, 177-221.